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Impacts of environmental change on agroecosystems and livelihoods in Annapurna Conservation Area, Nepal

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ABSTRACT

To understand local perceptions of the impacts of environmental change in two mountain districts of Nepal — Myagdi and Mustang — between 2010 and 2014, a survey, focus groups, town hall meetings, and extensive consultation with local stakeholders were conducted, supplemented by analyses of soil, rainfall, and temperature data. Mountain people in Nepal shared their perceptions of environmental change in their everyday lives, including agricultural practices and tourism activities. While ordinary individuals welcome the construction of new roads, elites still prefer to maintain trails and the status quo. People are concerned about the introduction of mosquitoes, increases in insect pests and plant pathogens, and other vectors along with roads. Snowfall has decreased and rainfall has been unpredictable. Mean minimum winter temperatures have increased and the mountains are experiencing shorter winters and less snow accumulation, which threaten the livelihoods of people that depend on fresh water. While people with means are replacing their traditional homes with modern homes, that is beyond reach for average Mustangi citizens. Expansion and diversification of agriculture, adoption of sound soil management techniques in Marpha village of Mustang and Shikha village of Myagdi, and growing forest cover in Shikha are some indicators of enhanced community managed practices. The coping strategies and indigenous practices adopted by local people in the region against hardship and environmental changes could serve as examples in similar mountain settings elsewhere.

1. Introduction

To some, Nepal is considered a living laboratory with its varied cultural practices and diversity of flora and fauna, made possible by the various microclimates that prevail in a small region of the country. The area, in less than 200 km, extends northwest from southeastern Nepal with an elevation of 60 m in Kechna Kalan to the Himalayas adjoining the Tibetan Plateau, with elevations over 8800 m. The geomorphology of Nepal includes three distinct regions: The Northern Region has 38% of the landmass and is dominated by the Himalayan Range with elevations of 5880–8848 m; the Central Region (36%, 1830–5880 m) is populated by river basins, mountain valleys, and Mahabharata Range; and the Southern Region (26%, 60–1830 m) consists of Siwalik Range, Chure hills, and

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inner *Tarai* (plains) (Shankar, 1999). Ninety percent of the precipitation in Nepal occurs during the summer monsoon (June to September), followed by a dry winter season. The average annual precipitation is 1516 mm with minimum of 210 mm in Mustang and maximum of 5460 mm in Pokhara region. The temperature in *Tarai* ranges from 4 to 44 °C, whereas in the Himalayas subzero temperatures are very common during the winter months (Shankar, 1999). Nepal is also rich in water resources with seven important river basins, including the three major ones — Karnali in the west, Sapta Koshi in the east, and Narayani in the center. Among the tributaries of Narayani, Kali Gandaki River, originating in Mustang Bhot *Himal* (mountain), is very important because of its year-round flow and the landscape around it.

The Kali Gandaki River carries large quantities of glacial deposits with high bed load yielding a black river, and forms the deepest gorges in the world, providing immense hydropower potential. Because it flows through central Nepal, the river is a cultural and geographical dividing line between the eastern and western Himalayas. To document indigenous practices and traditions in combating impacts of environmental change in Nepal, two different districts of Nepal were studied from either side of the Himalayas: Myagdi and Mustang.

Mustang is the least accessible district among the seventy-five districts of Nepal and 77% of the people there are involved in agriculture (National Trust for Nature Conservation (NTNC), 2008). Likewise, the economy of Myagdi is largely dominated by agriculture. Tourism is equally popular in both places because of the famous Annapurna Circuit trek that passes through them.

Textures of soils at the Mustang study sites were loam, silt loam, silty clay loam, sandy clay loam, and clay with most texture (58.9%) belonging to silty loam (Shrestha et al., 2017). Soil textures found in Myagdi are similar to its neighboring district of Prabat where most soils were silty loam (Khadka, 2012).

The importance of social, cultural, economic, spiritual, and moral aspects of a society in understanding the impacts of climate change on local people was discussed by Byg and Salick (2009) in the Eastern Himalayas. Byg and Salick (2009:165) also identified, "…models and other scientific instruments are not sufficient to understand or tackle complex problems such as climate change." Additionally, researchers found people's observations are deeply rooted in local traditional values and physical settings but are rarely documented in scientific literature even though they can inform global level processes and vice versa (Berkes et al., 2001; Laidler, 2006; van Aalst et al., 2008; Wilbanks and Kates, 1999).

The climate is changing in Nepal with greater intensity and impact on higher altitudes, such as in the Trans-Himalaya (Becken et al., 2013; Shrestha et al., 1999). The Tibetan Plateau is experiencing some of the highest rates of warming on the planet (Liu and Chen, 2000). Extreme weather events and unpredictable precipitation trends have been projected for the region (Nyaupane and Chhetri, 2009). People in the Lower Mustang Valley have witnessed shifting weather patterns, such as warming winters that have lengthened the growing season and extended it northward to the highlands.

While the demand for energy in the developed world will increase by 19% in the next two decades, the demand for energy will rise by 84% in developing countries by 2050 and 56% of this demand from developing countries will be attributed to India and China alone (Kitchen, 2014). Surrounded by China to the north and India in the other three directions and home to eight of the fourteen tallest peaks that are 8000 m in height or above, Nepal will likely feel the impact of the mounting energy demand and the effects of the associated greenhouse gases. Globally, the earth is warming and the first ten years of this century have been the hottest decade in history. Within the 100-year period from 1906 to 2005, the planet warmed by 0.74 °C and the rate of warming of the earth in the last 50 years has been 1.3 °C, double the rate of the whole century (Dessler, 2012).

The Himalaya is the source of fresh water for more than a billion people and 5–10% of the world's cereal crops depend upon it. Most of the currently accessible ice and snow supplying fresh water to the region will disappear in summer months by 2050 (Kitchen, 2014). Many Himalayan glaciers are losing ice more quickly than they can be replenished. Water shortages during summer months will impact irrigation and drinking water supplies. Forest fires may erupt in the dry season compelling people to migrate and tensions could rise in the region. Flooding and landslides in the rainy season may deteriorate people's quality of life. IPCC (2007) projects similar life-threatening forecasts for many parts of Asia, including a greater risk of diarrheal and infectious diseases, large-scale storms, typhoons, sea level rise, flooding and inundation, glacial snowmelt, extreme water events, collapse of sandy beaches, unusually high fire risks, and frequent landslides.

In parts of the mountain region of Nepal, very little is known about the factors driving environmental change there, how people are coping with the changes, what resources are in place to tackle them, and in what way people from various walks of life are impacted (Gentle and Maraseni, 2012). Accounts of local and traditional knowledge in climate change and its impacts have been greatly overlooked by many contemporary studies (Byg and Salick, 2009). Implementation of climate change policy has been rather slow in Nepal because of its formal and rigid bureaucratic process that doesn't prioritize adaptation activities (Chaudhury et al., 2016). In addition, the Local Adaptation Plan for Action instituted in 2011 in Nepal to incorporate climate adaptation in development planning and initiate climate resistant growth has encountered major hurdles, including ignorance of climate change, resource exploitation, and lack of political backing (Baral, 2013; Government of Nepal (GON), 2011).

To understand some of this gap, this paper utilized field-based methods and studied variables responsible for altering traditions and living conditions in Annapurna Conservation Area (ACA), Nepal. The ACA is the largest protected area of Nepal covering 7629 km^2 from 1000 to 8091 m in altitude in five of the 75 districts of Nepal and includes 57 village development committees with rich biological and cultural diversity (NTNC, 2009). The ACA is a model illustration of park-people cooperation in the conservation of natural resources, biodiversity, sustainable development, ecotourism, women's involvement in conservation, use of renewable energy sources, protection of cultural heritage, and community-based resources management. However, it faces challenges from the more than 100,000 people of various indigenous communities that inhabit the area (Bajracharya, 2012). To examine this topic more rigorously, we located study sites along the famous Annapurna trekking routes, including Shikha village in Myagdi and the towns of Lete, Marpha, Jomsom, and Kagbeni in Mustang (Fig. 1). Shikha is the southernmost study location. Jomsom and the other Mustangi

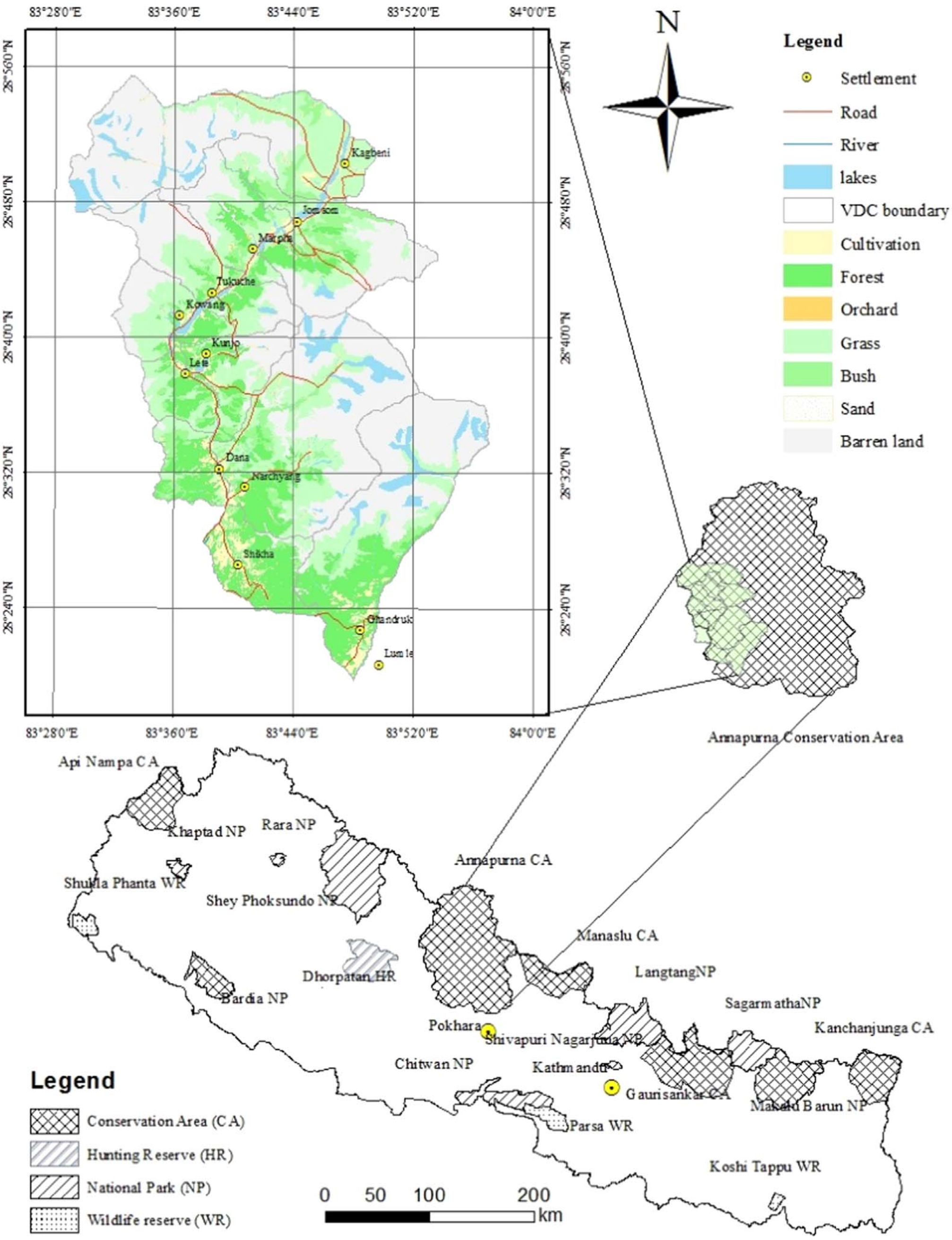

Fig. 1. Map of Annapurna Conservation Area, including research sites.

towns are close to the north edge of the study area.

The objective of this study is to understand local peoples' perceptions of the impacts of environmental change in Myagdi and Mustang between 2010 and 2014 and to determine if traditional practices are helping to cope with environmental challenges faced by local residents.

2. Theoretical approach

This study focuses on people's perception of climate change based on their local experience and the everyday lives of individual farmers, hoteliers, entrepreneurs, community leaders, policymakers, conservation officers, and government staff in the study area. Aligning with the research approach taken by Becken et al. (2013) of "practical wisdom," the two Nepali researchers and the corresponding author of this manuscript have spent several weeks in multiple years in the study locations since 2010 conversing with

and learning from seasonal farm workers, community leaders, trekkers, school teachers, and conservation officers and interacting with elders about their traditional belief systems and connecting the dots to understand local environmental conditions and attitudes.

While studies from the Arctic regions have provided valuable information on the local variations in climate change and its impacts (Fox, 2002; Kofinas, 2002), involving indigenous people and their experience can enhance what can be learned from global climate models and measurements (Byg and Salick, 2009). By bringing not only the local experience, but seasoned local experts that speak the language, share the traditions, believe in similar value systems, and can easily relate to the people from study locations (unlike similar studies that were carried out by expatriates or foreign researchers), this research adds more substance to the understanding of "social ecological systems" where issues from time-space geography intermix (Berkes, 2002; Holling, 2001).

The firsthand account of the impact of global changes in the study locations noted by Aase et al. (2009) and Chaudhary et al. (2007) were also relevant for the research. Various studies have applied social science perspectives in understanding environmental change utilizing viewpoints both regional and global to pin down the drivers of change. Aase et al. (2009), Becken et al. (2013), Chaudhary et al. (2007), and Nyaupane and Chhetri (2009) helped in authenticating the techniques and methods used in the research and offered systems approach needed to investigate problems that overlap in more than one traditional discipline and demand metadata analysis.

Because Jodha (1992) argued that inaccessibility, fragility, marginality, diversity, niche, and human adaptations are part of specificities distinguishing mountains from *Tarai* or lowlands, this research followed the unique characteristics that the study locations present in terms of remoteness, sensitivities, isolation, range of existing meteorological and cultural variation, the distinctiveness mountains offer, and people's ability to cope with a changing environment. Therefore, it's useful to understand and acknowledge the importance of different environmental factors and their impact on climate change in the region. While Sharma (2000) and Nepal and Chipeniuk (2005) studied the peculiarities of the mountain after Jodha (1992) in tourism development, Nyaupane and Chhetri (2009) claim that there is a need to elucidate the effect of climate change in the tourism and recreational sector. As people along the ACA trails heavily depend upon the flow of tourism, we anticipate that identifying the parameters that affect environmental change in the area will help fill some of this void.

3. Methods

The remoteness of Shikha and Marpha presented more difficulties in accessing the study sites. Preliminary investigations in both of the localities were performed in the summer of 2010 and follow up studies were conducted in the summers of 2011 and 2014. A detailed breakdown of qualitative, quantitative, and field-based methods adopted in the study is presented in the subsections below.

3.1. Preliminary study

The researchers first visited Myagdi and Mustang districts from July 11 to 18, 2010. This part of the study was crucial to understanding the gravity of the problem and for framing the research methods. During the visit, personal contacts were established along the Annapurna trekking route with Annapurna Conservation Area Project (ACAP) staff in its branch office in Shikha and local villagers, entrepreneurs, and leaders in Marpha and Jomsom. To get a better sense of the environmental challenges faced by locals in Mustang, it was important to interact with people from different community sizes, livelihoods, and distances from trekking routes. Thus, 10 households from Kagbeni (a smaller settlement), 33 households from Marpha (a medium settlement), and 40 households from Jomsom (a larger settlement) were surveyed on July 15, 16, and 17, 2010, respectively. There were 22 structured questions in the survey covering demographics, precipitation, agricultural practices, water and wastewater, energy, and solid waste topics. We implemented the questionnaire first in Kagbeni, then in the larger villages of Marpha and Jomsom. All three surveys began selecting households from the central point of the villages in four directions (East, South, West, and North) until the required number of households were met using cluster sampling techniques followed by systematic sampling (Dangi et al., 2011, 2015).

To understand the perceived impact of environmental change from different viewpoints, individuals with experience varying from a layman to a former assistant minister were interviewed using open-ended questions and a bottom-up approach (Table 1).

Table 1
Description of interviews conducted in study sites during 2010–11.

Individual/Groups	Title	Date	Numbers
Siddhartha B. Bajracharya	Executive Officer, NTNC	August 15, 2011	1
Kshetra Gurung	Officer, ACAP Branch Office, Shikha	July 13, 2010	1
Bhakti Hirachan	Former *Mukhiya* (headman), Marpha	July 16, 2010	1
Gajendra Hirachan	Hotelier, Hotel Majesty, Jomsom	July 17, 2010	1
Nar B. Hirachan and villagers	Former Assistant Minister of GON, Marpha	August 8, 2011	41
Shikha High School teachers and villagers	Shikha High School, Shikha	August 7, 2011	15
Chandra B. Thakali	Retired Civil Servant, Jomsom	July 17, 2010	1
Three elderlies (without names)	Retired Jomsom residents	July 17, 2010	3
Total			64

3.2. Field study

The field study conducted from August 4 to 16, 2011 afforded an opportunity to expand the findings of the preliminary study and identify the existing indigenous knowledge base used to preserve fragile environments in the mountainous region. Having gained firsthand accounts of difficulties local residents confronted along the Annapurna trekking route, we narrowed down the problems into three thematic areas: soil, water, and forest. Linking the problems with appropriate resource persons covering three of the five key national environmental problems of Nepal (water, soil, forest, solid waste, and air) may help address these issues.

During the visit, a survey of 16 households each was conducted in Shikha on August 6 and Lete on August 8. There were 33 structured questions in the survey arranged by topics including demographics, water, soil, ecosystem services, and other question types, employing the aforementioned cluster and systematic sampling design. Additional interviews conducted in 2011 were also listed in Table 1 above. Altogether 64 people were interviewed.

Moreover, to uncover any associated effects that agroecosystem and livelihood have had in natural resources, soil samples were collected from Shikha and Marpha. Six soil samples from each settlement were collected and analyzed. At each village, three of the samples were obtained from cultivated soil and three obtained from uncultivated soil. A 50 m transect was established at each collection site and samples were collected at 15 m intervals along the transect using a trowel to a depth of 15 cm. Soil organic matter (SOM; Walkley and Black (1934)), nitrate nitrogen (NO_3-N), and ammonia nitrogen (NH_3-N) were quantified in the soil samples. Soil organic carbon (SOC) content was calculated from the SOM data. Soil samples were carried in Ziploc bags from the field collection sites to the laboratory, dried for storage, and were then analyzed.

3.3. Focus group discussion and consultations

An extensive follow-up study of Shikha, Marpha, and Jomsom occurred from May 22 to 30, 2014. An interaction between villagers and the research group was organized at the ACAP building in Shikha on the evening of May 24, where local people shared their perceptions of climate change, and the researchers had the opportunity to ask questions. The interaction was well attended by elderly citizens, including mothers' groups. Also, treating the ACAP office as a central point of the settlement, earlier in the day on May 24, twelve focus group discussions were conducted with three households in each of the four directions. Based on the outcome of the field study in Shikha and to construct a collaborative knowledge, a set of three questions were asked in each of the focus group discussions, which lasted about 45 min.

On May 26, researchers interacted with Marpha residents in a town hall meeting attended by many current and former leaders, farmers, and schoolchildren as well as *mukhiyas*, mothers' groups, and Marpha Foundation (an organization working in the area). On the morning of May 27, the research group observed agricultural fields, learned how practices are shifting toward cash crops, inquired about the use of organic manure, and visited waste burning sites. The conversations with locals provided information related to soil quality, water quality, and air pollution. During the afternoon, an ACAP staff member from its Unit Conservation Office in Jomsom presented information regarding ACAP's conservation work to the research group and responded to queries. A separate consultation was held with district level officials, providing information on governmental efforts in soil management, climate change, erosion control, and riverbank management.

Each of the surveys and focus group discussions began after receiving oral consent from the participants to protect their privacy.

Moreover, temperature and rainfall data for Jomsom (study site), Lumle (near Shikha), and from a nearby urban settlement (Pokhara) were obtained from the Department of Hydrology and Meteorology (DHM, 2016, 2014).

4. Results and discussion

4.1. Factors affecting environmental change

While both Mustang and Myagdi met or exceeded the human development index (HDI) of 0.49 for Nepal in 2014, their adult literacy rates are an indication of their remoteness in relation to Kathmandu (Table 2). Despite being the second least populated district of Nepal with the total population of 13,799 (CBS, 2011), Mustang barely produces enough grain to support its population six months out of the year and the area has persistent poverty where 55.5% and 19.8% of the households are ultra-poor and poor, respectively, with a poverty deprivation index of 33 (NTNC, 2008). Even with their respective locations along the trekking route, a large majority of residents in Marpha and Jomsom were engaged in agro-pastoral activities (Fig. 2). As stated earlier, the district wide

Table 2
Human development report of Mustang and Myagdi districts of Nepal (UNDP, 2014).

Index	Mustang	Myagdi	Kathmandu	Nepal
Population	13,452	113,641	1,744,240	26,494,504
Life expectancy (yr)	65.04	70.05	68.55	68.80
Adult literacy (%)	61.35	65.16	84.04	59.57
Per capita income (PPP $)[a]	1922	1028	2764	1160
HDI	0.508	0.490	0.632	0.490

[a] PPP = purchasing power parity.

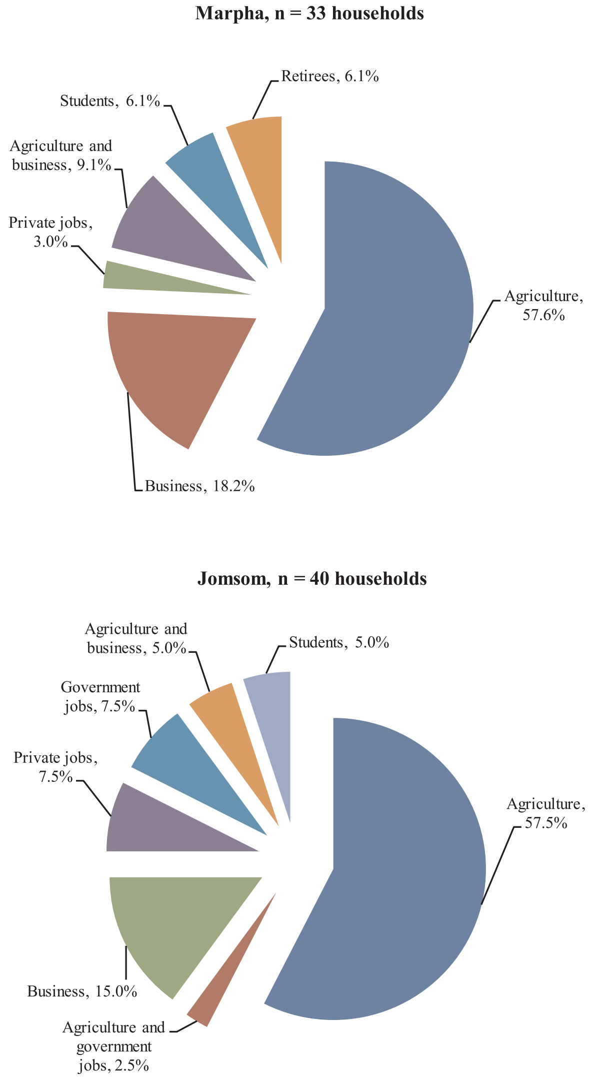

Fig. 2. Respondents' profession in Marpha and Jomsom.

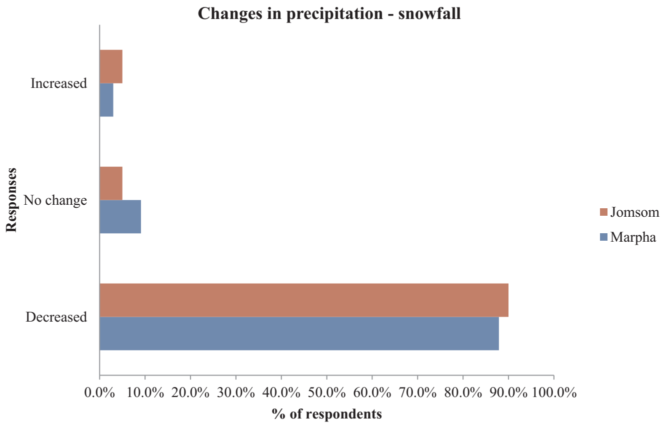

Fig. 3. Changes in precipitation pattern – snowfall.

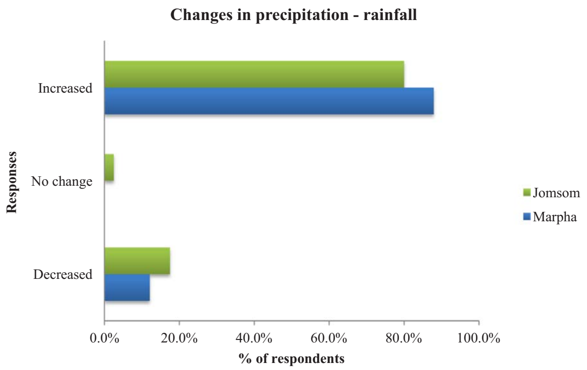

Fig. 4. Changes in precipitation pattern – rainfall.

average for involvement in the agricultural profession was about 77% (NTNC, 2008). Most respondents in both places were involved in agriculture; people occupied in business were the second largest group in Marpha and Jomsom. Jomsom is the seat of Mustang district, so some of the participants had government jobs. Businesses were represented by hotels, most often run by local Thakali people. Shops primarily consisted of gift stores operated by Tibetan migrants in the main business districts and tourism trails in Marpha and Jomsom. Because of the importance of a good snowpack to farming, domestic water supply, and ecotourism, a survey question was asked to elicit information on factors affecting crop production. In Marpha, 87.9% of the respondents (90% in Jomsom) indicated that snowfall has gone down and the same percentage of respondents (80% in Jomsom) believed rainfall has been more intense thus affecting crop yield (Figs. 3 and 4.)

The precipitation clock seems to be changing over time. For instance, Jomsom received an intense snowfall early in the month of *Kartik* (October-November) in 2007 (G. Hirachan, personal communication, July 17, 2010). An 82-year-old man mentioned he hadn't seen this in *Kartik* for long time. A nearly one-foot-deep snowfall took a huge toll on apple trees because of the excessive weight of the snow on juvenile leaves. A Jomsom native and retired civil servant also talked about soil erosion, increases in insect pests and plant pathogens, random precipitation, and depletion of drinking water aquifers resulting from diminishing snowfall and deforestation, and recalled that early snowfall in the month of *Kartik* was normal in Jomsom some forty years ago (C.B. Thakali, personal communication, July 17, 2010). In fact, the weather in 2007 was very strange in Nepal as Kathmandu received its first snowfall in 63 years on February 14, 2007 (Reuters, 2007).

Additionally, 90.9% of the survey participants in Marpha stated the temperature has increased and 87.5% mentioned the same in Jomsom. The most recent data from DHM (2016) concur that the mean maximum and minimum temperatures of Jomsom have indeed changed. The mean maximum and minimum temperatures were 18.66 °C and 5.4 °C in 1965, 18.44 °C and 5.72 °C in 2010 (at the time of the survey), and 17.77 °C and 9.93 °C in 2014 (during the follow up visit), respectively. The temperature readings are from Jomsom Airport located between the towns of Jomsom and Marpha and could represent both. It is apparent that the mean maxima have trended to the lower side, and the mean minima have clearly increased, thus supporting the findings of the survey. Another reason for public perception could be higher summer temperatures, for example in July 2010 while the survey was being conducted the mean maximum and minimum for Jomsom were 22.2 °C and 13.8 °C, respectively. People are also concerned about the changes, as three elderly Jomsom residents stated on July 17, 2010: "Now, winters are warmer and summers are colder. Our cropping pattern has shifted from naked barley (white), mustard, buckwheat, and wheat to tomatoes, eggplant, corn, and chilies." Both Chaudhary et al. (2007) and Dahal (2006) have recounted experiences by farmers in Mustang and its neighboring district, Manang, where they can now grow cauliflower, cabbage, chili, tomatoes, and cucumber without greenhouses.

Local people in Kagbeni reported on July 15, 2010 their perception that snowfall has declined in last 20–25 years from about half a meter to 10 cm; rainfall has decreased; the monsoon is delayed; crop production has dropped; floods are less frequent; Kag *Khola* (river), a tributary of Kali Gandaki River has become narrower and deeper making it difficult for people to cross; the flow in Kali Gandaki is shrinking; retreating groundwater has impacted the drinking water source; and irrigation, mosquito infestations, and fuelwood collection have gotten worse. People spend a whole day fetching firewood that lasts them merely a week. With the weakening precipitation in Kagbeni, crop yield for potatoes, wheat, and buckwheat has declined. Similar observations were shared by an hotelier in Jomsom who described that agriculture had been severely impacted because of emigration of youth from the area, which has left 50% of the land uncultivated.

The impact of environmental change has been more deeply felt in parts of the study locations. Eighty one percent of respondents from Shikha, and 75% in Lete, indicated that they had often experienced drought and/or floods in recent years. Evidence of a higher level of impact in Shikha was echoed by people in the neighborhood of Khopra Danda on July 13, 2010, who described that those engaged in sheep farming were no longer active because of prolonged drought and decreasing amounts of herbaceous grasses.

An insufficient water supply was a chronic problem in Shikha and Lete with a number of households stressing that either there was not enough water to begin with or it was a problem many months out of a year. The perception of reduced water supply was further corroborated by responses to whether there had been any changes in the rainfall pattern in the last few years or not, where 50% of the Shikha respondents answered yes with sometimes (Lete, 25%), 43.8% replied yes with usually (Lete, 56.3%), and 6.3% replied no (Lete, 18.8%).

Consultation with district level officials in Jomsom on May 27, 2014 identified shifting apple farming to the north due to the warmer climate, emerging pests and diseases such as apple scabies, damage of crops by armyworms, rising number of landslides, and increases in soil erosion and sediment load in the riverbed as key challenges for Mustang. While the increase in sediment load in the riverbed could make irrigation more difficult, Gauchan (2010) and Suryananshi (2016) reported that the prevalence of new diseases and a decrease in yield are the reasons why apple farming is moving to colder regions in the north. Similarly, Rai et al. (2015) concluded that the lack of cool weather has a direct bearing on apple production. Among the positive impacts of climate change reported by the officials were expanding apple farming to the north, longer vegetable growing season due to warmer temperatures, and shortened harvesting period. Adverse impacts of climate change described were less and erratic rainfall, diminishing snowfall, recent flooding, and shrinking drinking water supply.

Shrestha et al. (1999) project that dry seasons will become drier in the driest region in Nepal. Decrease in snowpack and deforestation has already impacted drinking water supplies in Marpha; people now have to rely on *Muhans* (sources of water) remotely located at higher elevations. With a greater evaporation rate and reduced snowpack in the mountains, the surface water flow in Kali Gandaki River could be impacted and this will have an immediate bearing on water sports and tourism (Nyaupane and Chhetri, 2009). Shrestha et al. (1999) showed a greater level of warming is taking place in the mid-mountains and Himalayan region than in the lowlands and *Tarai* and this could directly influence the river water flow. While Gentle and Maraseni (2012) stated that mountains are warming faster than global averages within last 100 years, Shrestha et al. (1999) established that in Nepal the Middle Mountain and the Himalayas have experienced temperature increases ranging from 0.06 to 0.12 °C per annum after 1977. Fujita et al. (1997) and Kadota and Ageta (1992) obtained similar results regarding diminishing snow cover and glacier extent in the Himalaya. Since the Himalayas are the source of fresh water and food for 1.3 billion people across South and East Asia (Kitchen, 2014), changes in snowpack will alter the livelihoods of people in the region. The ND-GAIN Index (2015) also placed Nepal as 55^{th} most vulnerable and 70^{th} least ready country among the 182 nations measured in six life-supporting categories – water, food, ecosystem service, health, human habitat, and infrastructure. Because Nepal has lost 6% of its glaciated area from 1970 to 2000 and 25% of glacial cover in northwestern China could be depleted by 2050, the 3 °C rise in temperature by 2100 projected by climate models could be disastrous for many people in this part of the world.

Forty years of rainfall data reveal Jomsom, in the Trans-Himalaya, receives the least precipitation, while Lumle and Pokhara both get much more rainfall than Jomsom (DHM, 2014). A ten-year average of precipitation patterns in these locations provides evidence that annual rainfall has decreased in all three places during 2003–12 compared to the previous decade (Table 3). Winter precipitation has gone down in Lumle and Pokhara in comparison to 1973–82 and 1983–92, whereas it has increased in Jomsom. The pre-monsoon rainfall has generally decreased in Lumle and Pokhara and has increased in Jomsom. The monsoons have become more intense in Jomsom and Lumle, while Pokhara has experienced a decrease in rainfall during 2003–12 compared to previous decades.

Shrestha et al. (1999) established a small but distinct increase in maximum annual temperatures in the Himalaya. A 32-year temperature data set obtained from DHM (2016) indicated mean maximum and minimum temperatures of Jomsom, Lumle, and

Table 3
Precipitation pattern (mm) in the last forty years in and near study locations of Jomsom, Lumle, and Pokhara.

Precipitation pattern	Location	Year			
		1973–82	1983–92	1993–02	2003–12
Annual (Jan-Dec)	Jomsom	251.59	214.7	286.25	280.4
	Lumle	4993.64	5345.33	5785.4	5436.4
	Pokhara	4026.43	3716.51	4362.87	3599.31
Winter (Dec-Feb)	Jomsom	18.62	17.83	37.78	24.71
	Lumle	87.85	115.07	106.72	87.67
	Pokhara	78.33	90.49	73.3	66.52
Pre-monsoon (March-May)	Jomsom	52.28	55.11	65.99	62.01
	Lumle	459.55	438.72	563.41	450.77
	Pokhara	562	442.32	646.37	521.94
Monsoon (June-Sep)	Jomsom	143.62	101.7	150.15	169.07
	Lumle	4205.79	4578.21	4865.44	4676.55
	Pokhara	3135.94	3044.51	3463.88	2830.02
Post-Monsoon (Oct-Nov)	Jomsom	37.07	40.06	32.33	24.61
	Lumle	240.45	213.33	249.83	221.41
	Pokhara	250.16	139.19	179.32	180.83

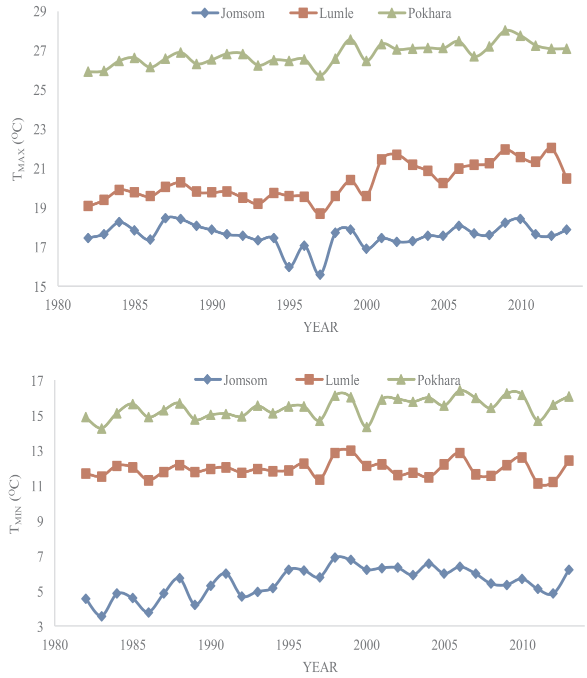

Fig. 5. Variation in mean annual maximum and minimum temperatures of the three locations.

Pokhara have climbed between 1982 and 2013 (Fig. 5). There is a clear trend that temperatures in the region are warming with the mean minimum temperature of Jomsom increasing by 1.64 °C in 32-year period, the most of the settlements, and Lumle's mean maximum temperature has warmed by 1.38 °C in the same period. These findings in Lumle (mountainous region) and Jomsom in the High Himalayas are consistent with the conclusions in Shrestha et al. (1999) that the mountains in Nepal are getting hotter and the first dozen years of this century have been the warmest on record since 1850 (Kitchen, 2014). The measured values for temperature (Fig. 5) and precipitation (Table 3) are consistent with our survey results.

There clearly are huge geographic differences in rain abundance across the Himalaya. Pokhara and Lumle have, respectively, 13 and 19 times as much rain as does Jomsom (Table 3). Obtaining similar time-trends from a larger number of locations (geographically dispersed) is essential for elucidation of any temporal patterns.

Climate change is global; responses are local. This is the conclusion reached by Becken et al. (2013) and Byg and Salick (2009) in studies of cultural responses to climate change in Nepal and Tibet, respectively. Rainfall is highly variable depending on geography, directions of locally prevailing winds, and the presence of topographic features that can induce locally wet or dry regions. Thus, temporal patterns may differ across geographically distinct regions in Nepal, adding greater urgency to obtaining temporal data from a large number of locations as suggested above.

Rainfall patterns are locally more highly variable due to topography and wind patterns than are temperatures. Therefore, regional trends in rainfall in the Himalayas will need to be done on a more geographically localized scale than was possible for the air temperature study of Shrestha et al. (1999). Becken et al. (2013) and Byg and Salick (2009) showed responses to climate changes are themselves highly localized and culturally mediated. To predict the effects of climate change on people's lives (as it pertains to

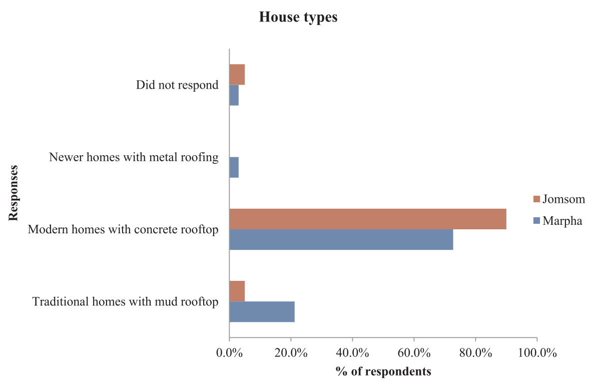

Fig. 6. House types in Marpha and Jomsom.

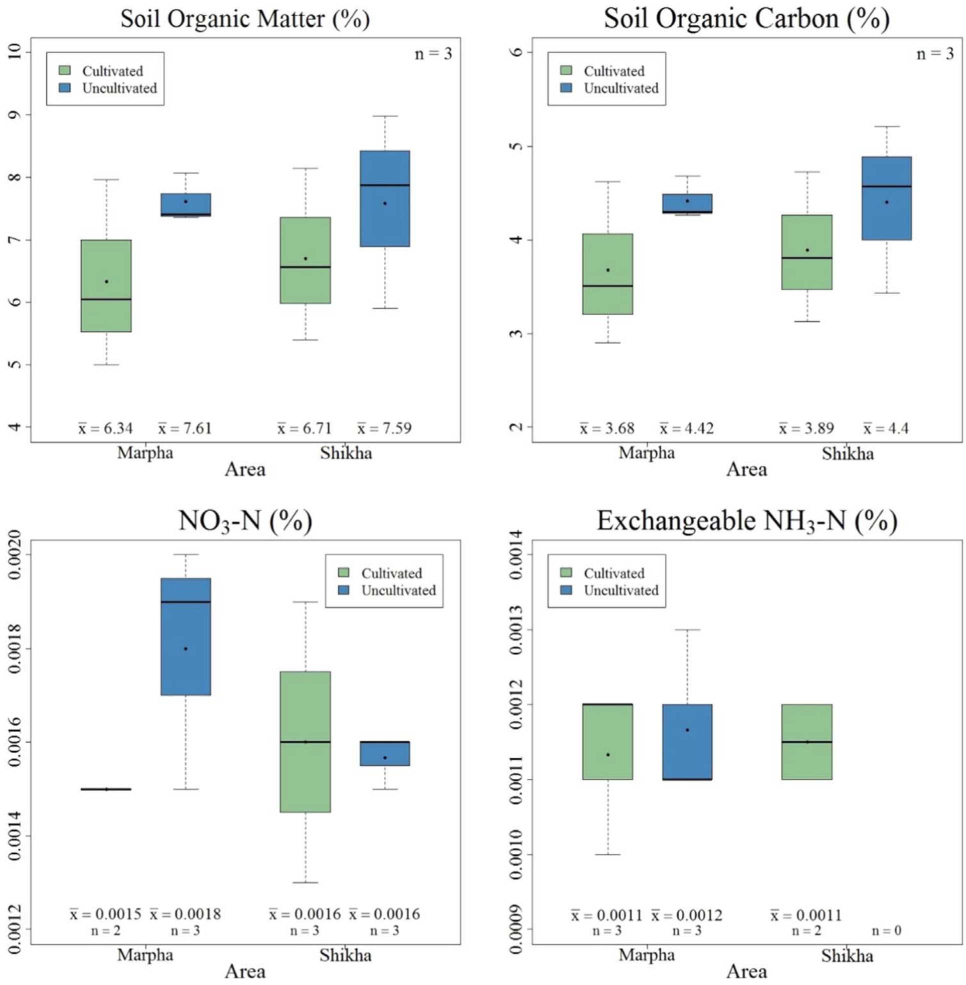

Fig. 7. Boxplots of soil variables from Marpha and Shikha.

rainfall), temporal and location trend data will be needed from a large number of locations, with attention to local geographies. At this point, it is not clear whether such data exists for Nepal, but pursuing such data and trend analyses could be important future work.

4.2. Effects of economic development, construction and expansion of roads, and tourism activities on livelihood

Research showed house types found in Marpha and Jomsom have changed from those that were traditional in the areas. Most homes in Marpha and Jomsom are now modern homes with concrete rooftops (Fig. 6). Nyaupane and Chhetri (2009) also concur that winter snowfall has lessened and spring rainfall has increased thus creating stagnant water on the flat rooftops of old-style homes made with mud and clay and erosion of structures, and this has noticeably affected motels and teahouses. Similarly, Dahal (2006) mentioned that unpredictable monsoons, diminishing winter snow, post-winter and unusually heavy precipitation in the summer months, and windier river valleys are causing roof leaks and wall damage to traditional mud-roofed homes.

On the other hand, there are good reasons to continue traditional farming techniques. In Marpha, 60.6% of the respondents and 50% in Jomsom perceived that crop yields have declined. Analyses of the soils of Marpha and Shikha indicated that cultivation resulted in significant losses of SOC. This is not surprising, as cultivation of topsoil has consistently been found to reduce SOC by studies around the globe. SOM consists of 58% SOC, so having both values go down with cultivation is expected. This is an important loss because approximately 95% of the nutrients in most soils are contained in the SOM. Lab results also indicate no statistically significant differences in the mean values of inorganic nitrogen, NO_3-N, NH_3-N, and between cultivated and uncultivated soils at both Marpha and Shikha (Fig. 7). This inorganic nitrogen represents the nitrogen available for plant uptake. Organic nitrogen in the SOM is usually the largest pool of nitrogen in most soils, so the differences in SOM between cultivated and uncultivated soil represent important disparities in soil nitrogen content as well as other nutrients including phosphorus, sulfur, and micronutrients. Although this data indicates there is some loss of soil quality as a result of cultivation due to loss of SOC, the cultivated soil still has a relatively high SOM and SOC content, suggesting the traditional agricultural practices used by farmers in Shikha and Marpha are sound and

Table 4
Yearly flow of tourists (in numbers) from Birethanti Check Post[a] (ACAP, 2013).

Year	Entry	Exit
2008	26,458	31,430
2009	29,269	34,174
2010	31,734	37,917
2011	38,054	40,526

[a] Birethanti is one of the entering check posts for foreign visitors arriving into the ACA located southwest of Lumle in Fig. 1.

should be continued.

Many residents still use fuelwood for cooking in both Marpha and Jomsom although liquefied petroleum gas (LPG) has been introduced in the area with the recent development of roads. From our survey, 90.9% of the households in Marpha (92.5% in Jomsom) obtain their energy from fuelwood. The collection of fuelwood from local forests has led to massive deforestation in the region.

Public needs such as availability of goods and services, healthcare, access to market, and organized distribution of drinking water are more directly available for individuals residing in or near towns located along the trekking route. All of the survey participants in Marpha and Jomsom stated that their drinking water comes from community taps, and 97% of the respondents in Marpha (100% in Jomsom) indicated their wastewater is discharged into a canal, which then goes to agricultural fields or drains into the Kali Gandaki River. A majority of respondents (93.8% in Shikha and 81.3% in Lete) stated they receive their drinking water from a tap and the same percentage in Shikha (93.8% in Lete) mentioned the taps are located within 0–30 min' walk from homes.

Road construction between Jomsom and Lo Manthang has impacted tourism in upper Mustang, where ~ 23 km of the construction was not finished and if completed, would destroy tourism (G. Hirachan, personal communication, July 17, 2010). The same observation was true for Jomsom as the flow of foreign visitors had drastically reduced. Moreover, an Executive Officer of NTNC, remarked, “We have not been able to address road issues. Money allocated for EIA [Environmental Impact Assessment] later went to Engineering of [Nepal] Army.” (S.B. Bajracharya, personal communication, August 15, 2011). NTNC (2008) reported road construction did not follow any of Nepal's existing environmental policies and the impacts include decrease in prices of essential household merchandise, business with Tibet, human trafficking, smuggling, and generation of solid waste. Now, solid waste is a growing environmental concern in both Marpha and Jomsom, where it is primarily burned in a simple grate furnace after some sort of collection and very little segregation. In addition, the consequences of not following environmental policies consist of frequent landslides, road closures, destruction of trails causing loss of revenue from trekkers, and air pollution.

The flow of tourists in the ACA has steadily increased (Table 4). In all of the four years examined, ACA exit numbers are greater than entry numbers, so exit numbers were used as a basis for comparison. When the flow was further broken down by months, it was found that in 2010 the exit number of 719 tourists for the month of July was the lowest. Historically, the two monsoonal months of June and July attract the fewest visitors. The finding aligns with the claim of G. Hirachan (personal communication, July 17, 2010) that the flow of foreign visitors had dropped at the time of preliminary study. NTNC (2009) also confirmed that the number of people visiting the ACA peaked in 2000 with 73,407 visitors, then fell, and regained numbers in 2008 with 72,175 visitors. The total annual numbers reflect the flow of visitors from all of the ACA entry points including individuals arriving via airplane in Jomsom.

In Shikha, 18.8% of the survey respondents blamed forest destruction/degradation on anthropogenic activities and 6.3% on those and other factors. The corresponding values in Lete were 43.8% and 18.8%. The larger number of participants in Shikha choosing not applicable (68.8%) than in Lete (31.3%) hinted that the forest cover in Shikha was healthy and still thriving deep into the ACA territory. This was also similar to the point that people in Swata made during the 2011 field study. (Swata is an adjoining village of Shikha to the northeast direction.) Being inaccessible with a direct all-season road, transporting chemical fertilizers could be very costly to the region; therefore, many people used organic manure that seemed to have helped the growth of forests and agricultural crops. It was more evident in Shikha because of the abundance of vegetation and crops that exist throughout the village. In an inquiry into the practices employed to enhance soil fertility in Shikha, 75% of the participants mentioned they used organic fertilizers, and 62.5% stated they did the same in Lete. Soil loss was still a problem in both places as a combined 81.3% of the respondents in Shikha and 75% in Lete answered yes with usually and yes with sometimes, in that order, to the survey question on this topic.

Focus groups yielded important information on public viewpoints about local environmental challenges and the ways the problems have accelerated within the last five years, as mentioned in Section 3.3 (Table 5). Fifty-nine individuals took part in 12 focus group discussions; the responses included votes for positive and negative outcomes from road construction, effect of climate change in agroecosystem, and dependency on the forest. Among the positive results concerning roads, transportation and healthcare and living standards each received the most votes at ten and increases in local tourism and property value both garnered only one vote. Within the negative results concerning roads, erosion and landslide was voted for most frequently at nine and impact of roads on price of goods, no change in property value, road accidents, higher expenses, lower income, and loss of biodiversity each got the lowest vote at one. Tomatoes and bitter gourd can be grown had the greatest focus group support at three regarding the positive results of impact of climate change in agroecosystem. Cold and less snowy winters; decrease in crop yield; drought, black snow, and hail; and rainfall pattern and intensity each scored the most support of focus group discussions for negative results of climate change in agroecosystem at ten, nine, eight, and seven, respectively. For people's dependency on the forest, the most positive votes were for

Table 5
Public responses of focus group discussion in Shikha on May 24, 2014. The numbers inside the parentheses indicate the number of times the response has been stated.

Questions	Positive results	Negative results
What changes have you observed after the construction of a new road in Shikha in the last five years?	Transportation (10) Market for local products (5) Higher price for potatoes (2) Healthcare and living standard (10) Cheaper goods (2) Employment (2) Increase in local tourism Exposure and opportunities (2) Population retention and new settlement (2) Increase in property value	Insecurity and cultural influence (3) Decrease in foreign tourism (4) Erosion and landslide (9) Deforestation and degradation (4) Pollution (2) Impact of roads on price of goods No change in property value Road accidents Higher expenses Lower income Depletion of agricultural land (2) Loss of biodiversity
How has agroecosystem production been altered because of climate change such as rise in temperature, variation in rainfall, and snow within the last five years?	Increase in crop production (2) Start of tunnel farming Initiation of mushroom plantation Tomatoes and bitter gourd can be grown (3) Opening of fisheries Introduction of cauliflowers and new beans	Decrease in crop yield (9) Disease in potatoes (3) Prolonged harvesting period Rainfall pattern and intensity (7) Severe weather and temp. (3) Cold and less snowy winter (10) Change in crop calendar (3) Shift in rhododendron flowering Drought, black snow, and hails (8) Pollution and mosquitoes (2)
In what ways has your dependency on the local forest changed within the last five years?	Less dependent (5) Growth of protected forest cover (3) Increase in private forest (4) Rise in use of wild vegetables	Requirement of permits (6) Curbed grazing and grass buy (4) Reduction in livestock (2) Restricted access to forests (7) Shortcoming in medicinal herbs Continued use of firewood Adoption of fossil fuels (5) Destruction of crops by monkeys

less dependent at five and the most negative votes were for restricted access to forest at seven.

Participants in Shikha on May 24, 2014, mentioned that roads ease access to transportation, reduce deforestation by making LPG available, bring markets closer to them, shorten the distance to hospitals or ambulatory care services, enhance the ability of elders to go to district headquarters to collect pensions, reduce dependence on firewood, help boost community forests and comprehensive management of natural resources, and allow people to market their grass along with firewood and fodder. The negative impacts described included degradation of forests during road construction, felling of trees, soil erosion and frequency of landslides, dust, use of roads limited to summer, loss of agricultural land, air pollution, cultural influence by outsiders, and a decline in tourism as travelers prefer to use traditional trekking routes. Also, community members gathered at the town hall meeting in Marpha on May 26, 2014 stated that apple and potato production have remarkably decreased and increases in insect pests and plant pathogens and climate change are compounding the problem.

4.3. Implications of traditional practices on environment

Traditional knowledge comprises the body of information, beliefs, rituals, innovations and practices of indigenous and local communities sustained and developed by native people, peasants, and communities in interactions with their biophysical environment (Berkes, 2004).

Such knowledge is embedded in social systems and coevolve with ecological processes (Gómez-Baggethun et al., 2013), can improve livelihoods (Chaudhary et al., 2007), sustain ecosystem services (Gadgil et al., 1993), and build resiliency in “social ecological systems” (Berkes and Davidson-Hunt, 2006). This type of traditional knowledge has generally been disseminated orally for generations worldwide and such practices are crucial for sustenance of environmental resources at the local level.

Moreover, the agro-pastoral system of the ACAP region is dependent on traditional agricultural practices and indigenous crop diversity. Conventionally managed agricultural productivity not only provides a major contribution to local consumption, but also substantially contributes to feeding the livestock in Manang and other parts of the ACAP region (Chaudhary et al., 2007). Animal husbandry is an integral part of the farming system; manure is an essential fertilizer (Aase et al., 2009). Like in other parts of ACAP, pine (*Pinus roxburghii*) needles in Shikha and juniper (*Juniperus communis, J. indica*) branches in Marpha are collected from the forest and used for animal bedding, which is then mixed with dung and urine and added to the manure heap.

Likewise, plants and plant products are the primary source of traditional medicine and nutritional requirements, and are highly valued resources in Nepal. Traditional medicine is the primary mode of healthcare for most of the population of ACAP, and local herbal practitioners called *Amchi* play an important role in healthcare and food security. There are more than 100 locally available

plant species used to treat different ailments and diseases (Bhattarai et al., 2010). These are some of the few remaining areas among the remote and mountainous districts of Nepal where Tibetan medicinal practice remains in use.

Farmers in Marpha have explored an avenue to cultivate an important medicinal plant, *Anacyclus pyrethrum* (locally called *Akarkara*), along with the apple orchards as a source of household income. It is regularly used in *Ayurvedic*, Unani, and herbal medicine worldwide for treatment of men's diseases, common cold, toothache, and has libido stimulant and aphrodisiac properties.

It was also noticed that local people in Shikha and Marpha are dependent on wild edible plant species and gather substantial amounts of wild plants to meet their daily nutritional needs. Several species are also used for trade. These include some species of the onion family (*Allium carolinianum)*, arum family (*Arisaema flavum*), asparagus family **(***Asparagus filicinus)*, and nettle family **(***Urtica dioica)*. A few, including wild onions, have high trade values. However, the traditional knowledge of the use of wild food plants is decreasing with the introduction of modern packaged food items in Mustang and Manang as in many parts of the world (Bhattarai et al., 2009).

Traditional knowledge is a valuable heritage for the communities contributing in a complimentary way to managing the resources in the ACA. But, people have shown concern regarding the uncertain status of the indigenous knowledge that is being lost due to global changes.

5. Conclusions

This research highlighted people's perception of changes in precipitation, temperature, weather pattern, livelihoods, agriculture, and tourism and identified the importance of traditional knowledge. The study supported the argument that the mountains in Nepal are experiencing extreme weather events and villages in Myagdi and Mustang districts of Nepal are dealing with the impact of climate change. Nepal presents a unique opportunity to study the effects of climate change on everyday life. Even then, the information about how environmental factors affect livelihood and subsistence living is limited. For centuries, the mountains presented barriers to the flow of knowledge and communication among indigenous people in parts of the Nepalese Himalayas as well as isolating them from the contemporary society of Kathmandu and *Tarai*. More than 82% of people in Shikha (Myagdi) (CBS, 2014) are from Magar caste and 84% of people in Mustang are Gurungs and Thakalis (NTNC, 2008), which may explain differences in belief systems, traditions, practices, and eventual decision-making. While a section of the public led by elites and entrepreneurs still prefer limited construction of roads in the *Himal*, ordinary citizens seem to be thrilled with new roads, piped water, cooking gas, and electricity. While people seemed to be concerned about the outbreak of potato diseases, introduction of mosquitoes, deforestation, decrease in snowfall, inconsistent rainfall, leaks in roof-tops, northerly migration of apple farming, rise in temperature, droughts, and loss of tourism along the previously established trekking trails, their responses appear to be positive for shorter harvesting periods, longer growing seasons, expansion of forests in Shikha, accessibility to markets and healthcare facilities, and prolonged tourism activities during drier periods. A majority of people in Marpha and Jomsom are still engaged in agro-pastoral system despite being at the hub of the renowned ACA trail. Solid waste generated may have received some attention from the ACAP; the issues with water and wastewater still dominate in Marpha and Jomsom. Drought is an ongoing problem in both Shikha and Lete.

Traditional knowledge is being lost due to environmental and social changes. Presently people seem to be well informed about environmental changes; however, there is a disconnect between government authorities, policymakers, and experts in tackling the effects of changing weather on local livelihoods. The expansion of meteorological stations to gather time and place specific temperature and precipitation data and persistent engagement among the local people, scientific community, and government could help address some of the global issues these innocent mountain communities are facing in Nepal.

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